A DESIGN METHOD FOR PARTS PICKING ZONES IN A MANUFACTURING ENVIRONMENT

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Table of Contents

1. Introduction

1. 1 Introduction

Not a lot has been written about order picking in manufacturing environments. In this environment the picking process takes place in the so-called supermarkets. Order picking has been defined as the activity by which a small number of goods is extracted from a warehousing system, to satisfy a number of independent customer orders.In this case, the costumers are the assembly lines and the orders, the material requirements of these ones. This activity needs a great amount of manual work and is responsible for half of the costs of the warehouse in some cases (de Koster et al., 2007). Small improvements in this area can, therefore, lower the costs ofmaterial handling considerablyand thus, Supply Chain associated costs.The selection of an order picking system (OPS) is usually very complex and depends on many factors such as material properties, economic constraints, environmental constraints, system requirements, operating strategies and transaction data (Yoon and Sharp, 1996). However, decision algorithms have already been created to make this task at least easier.

The main aim of this thesis is to provide a tool that can easily give valuable information to make the election of an order picking system easier. Thestarting point will be an existing model created by researchers of Gent University. This model contains throughput, space and cost calculations for various OPS: Flowracks, VLMs, Vertical and Horizontal Carousels. A fifth throughput model will be created to calculate the throughput of an AS/RS as well as required floor space for the system. By doing this, all existing OPS will be taken in account in the model and the conclusions derived from the results will be more precise. The final step will be to validate the model by comparing it to real data obtained in a manufacturing firm. By using the modified design tool, different designs of the supermarket area will be proposed for this real scenario and all of them will be evaluated in terms of throughput, number of operators required and floor space required.

1.2 Literature Review

In “Design and Control of Warehouse order picking: a literature review”, R. de Koster, T. Le-Duc and K.J. Roodbergen, a general explanation of the picking process and different picking systems is made. The authors start with basic concepts in this matter and bring a classification of all the existing picking systems that can be found in a warehouse. The paper, however, focuses on low-level, picker-to-parts order-picking systems employing humans which is not of great interest in this case since the center of attention in this project are the parts-to-picker systems. The classification of the order picking systems is used in this thesis though.

“A structured procedure for analysis and design of order pick systems”, S. Yoon, P. Sharp provides a tool for the design of these kinds of systems. In the first part, they analyze the factors affecting the design of the OPS and also create some simplified models (see figures 4.1 and 4.2) to easily understand the overall structure of the systems and the product flows that go through them. In the second part, a design procedure for an OPS is presented with three stages and some sub-stages in them. This procedure will be followed in this thesis in the case study to design a supermarket area for an assembly line. Three main stages form this procedure: In the firs one, all the constrains that will affect de design have to be identified, then groups of products are created and each of them is assigned to a particular system. The last step will be to validate the results using simulation.

"Design of order picking system", F. Dallari; G. Marchet and M. Melacini, presents a decision model for choosing an order picking system based on empirical analysis of the results obtained from a survey carried out in 40 distribution centers. Results show that volume activity (expressed by order lines/day), the number of items and the average order size are main parameters for the selection of OPS. Also a decision tool is proposed in order to guide users in the first parts of the order picking design, this tool is an improved version of the one made by Yoon and Sharp in 1996. A fourth stage has been added to the procedure and some of them have been re-organized.

Another publication that is of major importance to this study is "A design method for parts picking zones in a manufacturing environment" by Klaas Peerlinck, Tim Govaert and Hendrik Van Landeghem. The main goal of this model is to design an order picking system for manufacturing environments consisting in four steps. In the first one, the input data is entered (weight, frequency, parts per product, part id and volume), calculations are then made to determine the throughput reached, the required floor space and the costs associated to the system. These results can be used as a decision support in designing the order picking system. The system that reaches the throughput conditions offering the minimum operational cost is the best election. However, as it has already been said, the ultimate selection of an order picking system includes other than economical constrains. This design tool will be used in this thesis and modified in order to provide throughput and space requirement calculations it will be explained with more detail in chapter 2.1.

The calculations for the throughput of this last model are based on the paper "A throughput model for carousel/VLM pods", Russel D. Meller and John F. Klote. This publication calculates not only the throughput of one device but also the throughput of a picker using more than one of them (what is known as pod). So it takes in account not only the retrieval time of the machine but also the time required to pick the items. Another model in Excel has been created using this model so the user can try different number of pickers and pods and see if the results match his/her throughput and capacity constrains. Although both models are quite alike, the first one also offers the feature of dimension calculations whereas in this one, the dimensions have to be optimized by trying different combinations of pods/pickers.As a positive feature it includes a non-random storage mode and a variable pick time mode to make calculations more accurate.

Concerning the Automatic Storage and Retrieval Systems, there are some publications by Yavuz A. Bozer and John A. White. In "Travel-Time Models for Automated Storage/Retrieval Systems" both the single command and dual command cycle times are calculated for an AS/RS system. The single command cycle consists in the crane going empty from the input/output area to a pallet space and then returning to the first one with a pallet, whereas the dual command cycle takes place when the machine goes from the input/output area with a pallet, deposits this one in a shelve, grabs another one and leaves it in the input/output area. It also considers alternative locations for the Input and Output zone and gives dwell-point strategies for the storage/retrieval machine. However, the most interesting publication concerning this thesis is “Back-of-the-Envelope Mini-load Throughput Bounds and Approximations” from the same authors. This model takes in account the equations obtained in the first model but adds the picking action to the model. This model does not exactly represent the AS/RS system studied in this thesis but with further modifications it will be very useful for it. This paper also includes an algorithm to optimize both the number of aisles and the size of the racks.Due to its importance to this thesis, these publications will be explained more carefully in chapter 2.

“A survey of literature on automated storage and retrieval Systems” by Kees Jan Roodbergen and Iris F.A. Vis is a publication that focuses exclusively on literature about ASRS. In the first part, there is an extensive classification of ASRS by type of crane, rack or handling system and also a chapter that is an overview of the decisions to be made while designing an ASRS. In every point of ASRS design (sizing, storage assignment, batching, dwell-point location, sequencing, performance measurement), there is an in depth review of the literature existing. This paper is interesting because it gives a very comprehensive overview of these devices.

1.3 Classification of Order Picking Systems

The main criterion to classify the order picking systems is whether the parts are the ones that move to the picker or vice versa. Thus, the systems are known as picker-to-parts or parts-to-picker:

The parts-to-picker are automated systems that allow good performance in certain situations because they save the walking time to the picker and therefore can reduce the order picking time up to 50% (Tompkins et al. , 2003). They also contribute to saving space in the picking areas because the parts are stored in high positions and when they are required, the system brings it easily to the picker. The most important systems of this kind are:

- VLMs: This stand for Vertical Lift Module. This system consists of several shelves distributed in the two faces in a cupboard-like structure. There is a crane that moves only in vertical direction and this is used to pick the trays and bring them to the pick space. This space is a rectangular hole that allows the picker to reach for the parts needed. There can be several boxes in one tray, so there is a chance that the picker can find two different lines in one tray. There can be space for more than one tray in the pick space in some units. In this case, the crane can retrieve the used tray and replace it for the new one while the picker is picking from the other tray in the picking space.

- Vertical Carousels: These modules are quite similar to the VLMs but just with one main difference: instead of having a crane that picks trays, the system consists in a wheel with a lot of trays. The picker also picks the different items through a picking space just like in the VLM. When the picking action is finished, the carousel spins till the next tray is located in the picking space. Some disadvantages exist with this method compared to the VLM system. The most important is that some units can spin in only one direction so if the next tray to be used is located just after the picking space, the wheel has to rotate almost a whole cycle to allow the picker to use it. The cost of the units is, however, lower than the VLM and it allows a similar saving of picking surface.

- Horizontal Carousels: The Horizontal Carousels are basically vertical carousels but instead of storing the boxes in a vertical position they store them in several layers but horizontally. The system could be described as a spinning flow racks that bring the bins to the picker instead of being this one the one that has to walk. They do not save the same space as the VLMs or the Vertical Carousels and they present the same disadvantages as the Vertical Carousels compared to the VLMs.

- AS/RS: The Automatic Storage and Retrieval Systems can be used to retrieve pallets or boxes (they are called mini-loads in the second case). There are several layers of pallets stored in racks and there is a crane running both horizontally and vertically through the aisles. When using these systems to perform the picking task, the crane picks the units and deposits them in the Input/Output (I/O) area. Then, the picking can be done directly or other transportation units can move the pallets or boxes to the picking area.

When these systems are used to do the picking task, the modules (specially the VLM, Horizontal C., Vertical C.) are organized in pods. A pod is a group of modules that is assigned to one picker. This way the picker utilization can increase because the idle time of this one is less. Now the operation of a pod is described: A batch of orders is assigned to each pod, each order can be divided in order lines, that are the different kinds of parts needed for that order. An order line also consists of several parts that can be needed of this particular kind. It is important to keep these concepts in mind because they will constantly be used in this thesis.

The other kinds of systems are the ones known as picker-to-parts and are basically racks. The racksare shelves where bins or boxes full of parts lie. There are two kinds of ways to do the picking in these modules:

- High-level picking takes place when the parts are stored in considerable height. The picker needs to use a crane to access the products. This system allows better space utilization. In this configuration, the picking action is usually performed in a different area so the area of storage can be smaller.

- Low-level picking is when the picker takes the parts directly from an aisle. Several kinds of racks are used in this type of picking such as simple racks, gravity flow racks and bins. In gravity flow racks, the replenishment is done in the upper part of a ramp and the picking is performed in the lower part. When a box is finished, it is removed and the ones in upper position move to the front.

In these kind of systems further optimization can be carried out by means of routing algorithms, items allocation policies and paperless operations using radio frequency or voice picking devices. Therefore, the picking productivity strongly depends on also the utilization of the aforementioned optimization drivers (Dallari et al., 2008).

There exist, however, publications that show other kinds of systems. That is the case of the pick-to-box system and the pick-and-sort one (Dallari et al., 2008). These systems have in common that unlike the ones mentioned earlier, they use a conveyor system to connect picking zones.

- The pick-and-sort system pickers in the picking area retrieve the amount of items of a line required for a number of orders depending on the batching policy. The parts are transported in a conveyor belt and sorted so that every destination bay corresponds to a costumer order. With these systems the batching is usually high so a lot of orders are included in the batch (at least

20). The productivity in these systems is usually higher that the productivity of a picker-to-parts system, as the picking locations are visited less frequently, therefore reducing the picker's travel time. This reduction is greater as far as the pickers operate in a small part of the forward area (Dallari et al., 2008).

- In the pick-to-box system zones divide the picking area and each picker is assigned one zone. All the items picked are then put in boxes on a conveyor belt. These boxes correspond to a costumer order so no sorting is necessary later. The boxes will be distributed and sent to their destination. As in the last system, the reduction of the forward area in smaller zones lead to a reduction of the walking time of the pickers.

There is a last system that only uses automated mechanisms to perform the picking task. The main difference between this system and all the other ones is that it does not use pickers to perform this task. This system is only used in special cases such as with valuable or small and delicate items (de Koster et al., 2007).

Although they will not be studied in depth in this thesis, it is important to talk about the information systems that can be implemented in order to both increase productivity and eliminate errors specially in the picker-to-parts systems. Before these information systems existed, the picker was handed a paper list of the products to retrieve and the quantities of product per batch. The information systems let the picker also know the location of the products, the sequence in which they have to be retrieved and the location where they have to be deposited. Some of these systems are:

- Pick by label: The picker receives the sequence of the items to be picked per batch as well as labels that have to be stuck to the picked products. At the end of the batch, remaining labels will denote a mistake in the picking.
- Bar codes: They can be used to identify a pick location as well as the parts that need to be picked.

- Radio data terminals: That combined with bar code scanners can transmit information easily and thus, avoid unnecessary walk time by the picker.
- Pick to light: A luminous dispositive is placed on the SKUs to be retrieved increasing therefore the speed needed by the picker to find the location. There can be used both to retrieve and to deposit the picked goods. In this last case the system is known as put to light.
- Voice technology: The picker hears the instructions of the items to pick from a computer using headphones, the picker can also speak through the microphone to confirm that the operation is successfully completed.

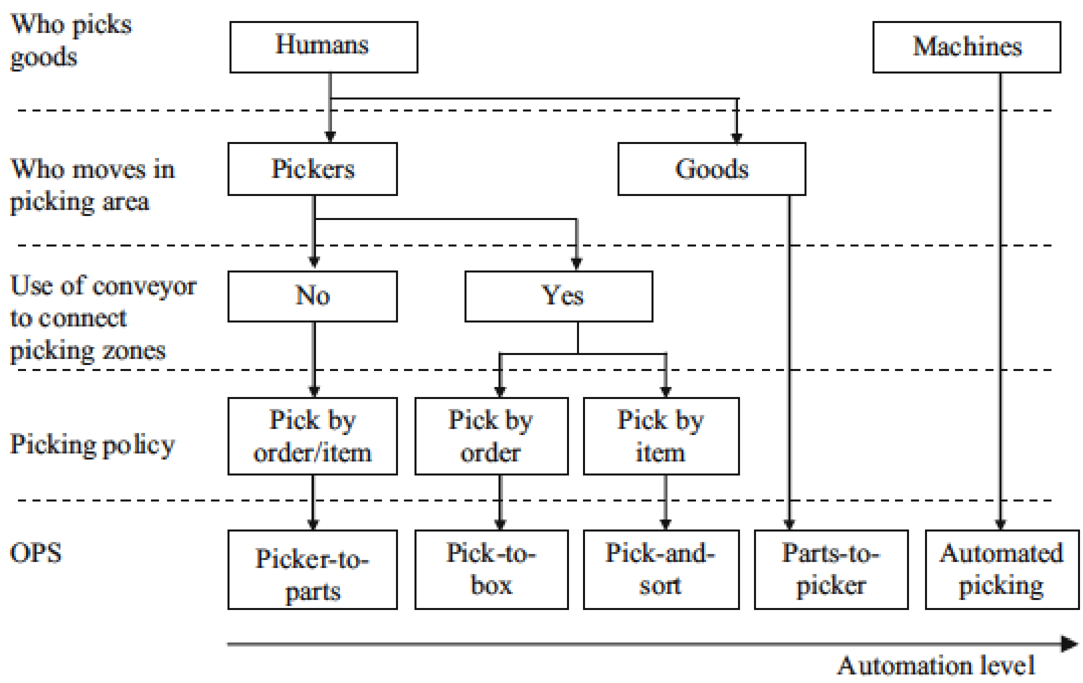

Fig. 1.1- Classification of OPS, from "Design of order picking systems" (Dallari et al., 2008)

2. AS/RS model

2.1 The existing flow rack, VLM, and carousel model

This model is the starting point for this thesis, and is the base that will be modified to achieve the objectives of this work. The model is implemented in Excel and it has a first sheet in which the user introduces the part data in a table. There is also one sheet to introduce all of the types of emballage and its dimensions. The restrictions that make possible the classification of the products in families are also to be introduce by the user in a separate sheet, so are as the details for the items that are case-picked, that means that the operator will pick the whole box of parts instead of one part at a time. There is input data of also the shift duration, cycle time, inventory required, working days per year… It is also possible to eliminate one or more families with a tool that allows filtering by frequency, size and emballage type, modifying the requirements following these requirements. With all this information, calculations are made in order to determine certain parameters that will be necessary for the throughput models as: shelves needed, parts per line, throughput required…

These calculations go to the different throughput models for the different modules, namely VLM, Vertical Carousel, Horizontal Carousel and Flow racks, each of them in a separate sheet. In every sheet, more input parameters are required such as dimensions of the module shelves/bins, pick time, setup time (needed for every batch), walking time, speed of the module, lines per batch, number of pickers, number of modules… The sheets are designed so that the user can easily introduce all these parameters, those are known or can be known easily by looking at the manufacturer's sheet of specifications for the module or just by observation. All this parameters are used to calculate the throughput of the module and is compared to the required throughput. Also calculations of the floor space requirements are made.

Although cost calculations are also available in these sheets, the costing models are not fully developed resulting in very approximate estimations of the cost of the system. The costs that need to be introduced by the user are the floor space cost, the cost of the modules and the cost of work labor. The cost of the whole system is then displayed as well as a cost evolution for the system in a separate sheet that, as previously said, is a very approximate estimation. That is the reason why the cost of the system will not be used in the design stage as constrain.

It has to be mentioned that this model was not made for designing a picking or warehouse area with more than one type of module. Also there is no possibility of filtering by multiple criteria, for example storing the fast moving boxes in one type of unit. Modifications will be introduced later in order to allow these features that will be needed in the design part. The input stage will not be modified but the calculations will be separated depending on where the user chooses to store what products.

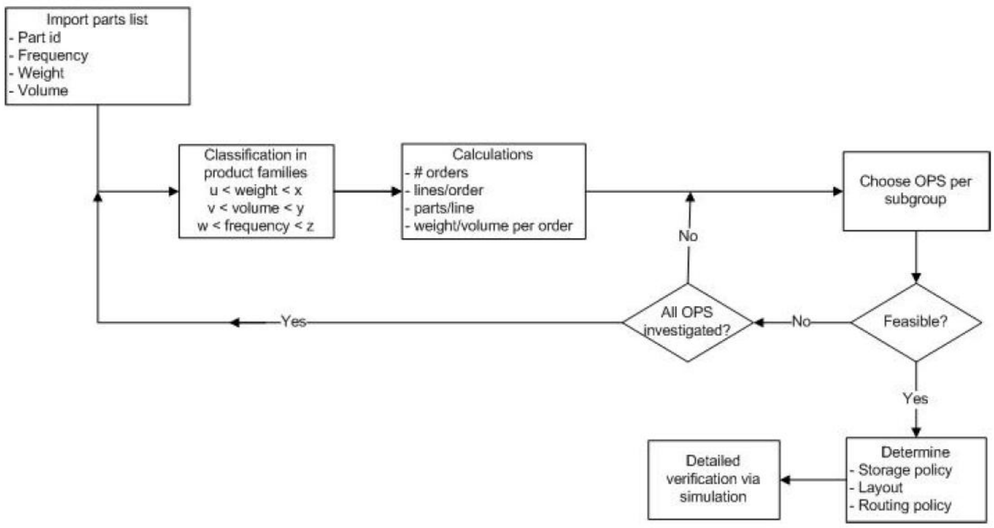

Fig. 2.1-Flowchart of the OPS design method, "A design method for parts picking zones in a manufacturing environment"

2.2 Definitions of ASRS

Some concepts must be explained before beginning to talk about de AS/RS model. The Automated Storage and Retrieval Systems are lifts that can move in both vertical and horizontal direction simultaneously. Although some of them can handle smaller units such as boxes (they are called Mini-loads), this thesis will focus on the ones that operate with full pallets. This system can accomplish many functions such as the storage function, the input/output function or the order picking function. Although the case studied is order picking, the model has been implemented assuming the input/output function is the one performed.

In this function, the system brings the pallet to the input/output point, and the pallet is carried to the picker by another automated system such as conveyors. When the picking action has been done, the pallet goes back to the I/O zone where a lift will store the pallet. This sequence can be pictured as a closed cycle, however, there are incoming flows of new pallets and outgoing flows of empty pallets, and those would represent the replenishment function. This system is shown in figure 2.2.

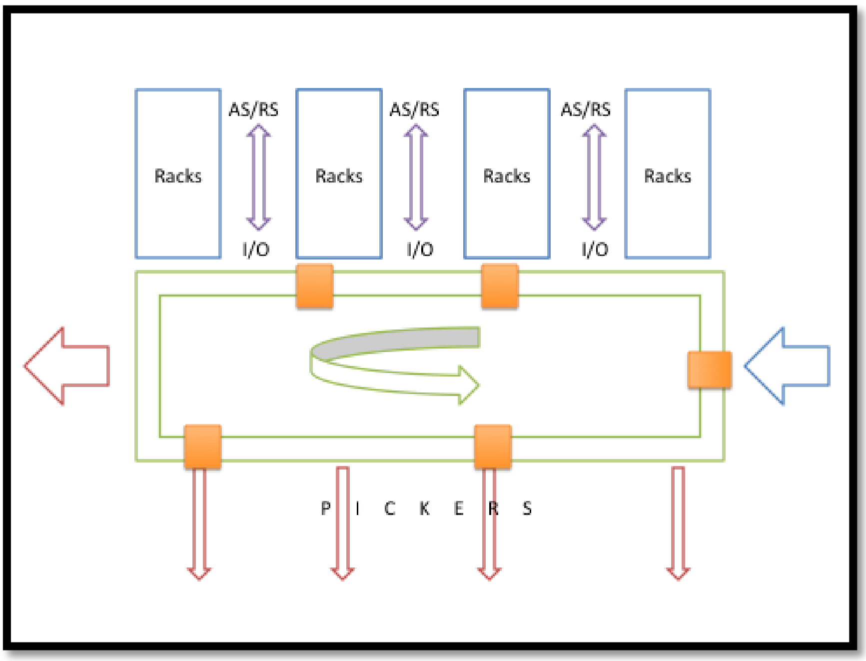

Figure 2.2- Representation of the AS/RS – picking system

2.3 The travel-time model

The throughput model used is based on the Bozer, Yavuz A. AndWhite, John A. 'Travel-Time Models for Automated Storage/RetrievalSystems' (1984) and also in 'Design and Performance Models for End-of-Aisle Order Picking Systems', by the same authors. First, the models will be described as well as the assumptions made by the authors and then the adaptations that have been made to adapt the models to the one in this thesis.

The first model describes the time required to perform both a Single and a Dual cycle command. The single cycle time represents de action of moving from the I/O point to one random point at one shelf and returning. The dual cycle action is the time needed for going from de I/O point to one random shelf, from this one moving to another random shelf and then returning to the I/O point. The assumptions made by the authors are the following:

- The rack is considered a continuous rectangular pick face where the I/O point is located at the lower left-hand corner.
- The S/R machine operates either on a single or dual command basis.
- The known variables are the rack height and length as well as the vertical and horizontal speed of the crane.
- The crane travels simultaneously in vertical and horizontal direction.
- Randomized storage is used.
- Pick-up and deposit times are ignored.

With the input variables the variables *th* and *tv* are calculated that are the time required to furthest position namely the upper right-hand corner. Then the variable *T* is described as Max (*th,tv*).

With *T* a new variable is described as b=Min (*th/T, tv/t*) that would take values between 1 and 0 and is named as “shape factor”. The probability density function for the single cycle command is calculated for the time in both directions for the crane to reach a random storage/retrieval position. It is then integrated to calculate the expected travel time of the single command cycle. The final results are shown now:

$$E(SC) = 2 \int_{z=0}^{1} z\, g(z)dz = \frac{1}{3} b^2 + 1$$

Operating in a similar way the expected travel time for a dual cycle command is as follows:

$$E(DC) = \frac{4}{3} + \frac{1}{2} b^2 - \frac{1}{30} b^3$$

In the last part of this paper, the models are tested and compared to the previously existing discrete models (remember that this is a continuous model) and the maximum deviation of this model is 100 times lower than the maximum deviation of the previously existing models. Due to its accuracy with diverse shape factors (*b*)and simplicity, this will be the model used to calculate the travel times in this thesis.

2.4 The initial throughput model

The second model by these authors use the timescalculated previously to create a model for order picking in a mini-load system. This system consists in several aisles in which a crane operates. At the end of each aisle, there are two shelves where two boxes can be stored for each aisle. Only one picker is assigned to each aisle. The assumptions made by the authors are:

- The rack is considered a continuous rectangular pick face where the I/O point is located at the lower left-hand corner.
- No acceleration or deceleration time is considered and the crane travels both in vertical and horizontal speed with continuous speed.
- The machine performs only dual command cycles starting and ending in the I/O point.
- Every trip involves two pick-up operations and two deposit operation.
- The two storage positions at the end of the aisle are identical in terms of container handling and AS/RS travel time.
- In retrieving a container the crane is equally likely to visit any point in the rack.
- The containers for each order are retrieved consecutively and in a random sequence. The last two containers of each order are interleaved with the first two containers of the next order.
- The throughput of the system is expressed as the number of pick per hour.
- The pick time is independent from the S/R cycle time.
- If more than one aisle is required, then each aisle is identical in terms of size and average activity.

A single aisle is modeled as a two-server closed queuing network with the number of pick positions representing the number of costumers in the system and the AS/RS and picker representing the two servers. The service time for the AS/RS consists the time required for the crane to store an old container and pick a new one. With this kind of system, the slowest part to do the process will be the one that determines the cycle time:

$$CT = \text{Max (pick time, S/R machine cycle time)}$$

Pick time can both be considered deterministic or exponential. Keeping in mind the results obtained in the previous model, the S/R cycle time can be calculated with a simple expression. Rather than considering the exact distribution for this time, the model approximates the performance of the crane taking the mean and variance of the travel time. Using simulation, Bozer determined the standard deviation for de Dual Cycle command:

$$S(DC) \approx (0.3588 - 0.1321b)E(DC).$$

A uniform distribution is chosen to represent the crane travel-time so the time is supposed to be between *k1* and *k2* with a mean of E(DC) and a standard deviation of S(DC), where:

$$k1 = E(DC) - \sqrt{3}S(DC) \text{ and } k2 = E(DC) + \sqrt{3}S(DC)$$

If the AS/RS time is uniformly distributed between $t1 = k1 + C$ and $t2 = k2 + C$, where C is a deterministic handling time of the crane and the pick time is deterministic, the expected value for the cycle time or E(CT) is can be represented as:

$$E(CT) = \begin{cases} E(DC) + C & \text{if} \quad 0 < p < t_1, \\ \dfrac{p^2 - 2pt_1 + t_2^2}{2(t_2 - t_1)} & \text{if} \quad t_1 \leq p < t_2, \\ p & \text{if} \quad t_2 \leq p < \infty. \end{cases}$$

Where p stands for the picking time.

2.5 The adapted throughput model

As it has been said, the previous model has been adapted to represent the system that concerns this Thesis, a AS/RS that manipulates pallets and deposits them on a conveyor belt to be picked next by pickers in picking bays. It has been achieved by using the following modifications:

- The known variables are the #lines/batch, #items/batch, the rack length and height, the vertical and horizontal speeds of the crane, the acceleration and deceleration times, the deposit/retrieval time and the pick and setup times.

- The buffer space in both the I/O point and the picking bays is considered sufficient for a whole batch. As a consequence, the time calculated will not be the cycle time but the batch time. The following expression illustrates that point.

  CT = Max (batch pick time, S/R machine batch time)

- The number of cranes and pickers is independent, the assumption that only one picker is assigned to an aisle is no longer valid.

- The total batch pick time can be calculated with the pick time and the number of items to be picked by batch. There are, however, some limitations in the weight of the objects to be picked, namely the objects heavier than 12 Kg are picked with special equipment. To model this fact, a percentage has been created by measuring the frequency of the objects heavier than 12Kg:

$$Weightcoef = \frac{\sum Heavyobjectsfreq.}{\sum Allabjectsfreq.}$$

Then, the total pick time per batch has the following expression:

$$p' = \frac{\left[\# \frac{\text{items}}{\text{batch}}.\text{pick time} + \text{setup time}\right]}{\#\text{pickers}}$$

Where *pick time* is:

$$Picktime = normalpicktime.(1 - weightcoef.) + heavyweight.(weightcoef.)$$

The setup time is a fix time needed per batch for the operators to make some administrative actions and prepare for the next batch.

- The total S/R pick time per batch is calculated as:

$$\text{E(S/R bt)} = \frac{\# \frac{\text{lines}}{\text{batch}}.\text{E(DC)}}{\#\text{cranes}}$$

- It has been considered that there is only one line per pallet so the number of stops is the number of lines per batch plus the extra stops needed in case the amount of items in one box is insufficient to cover the costumer needs. A study has been carried out to determine this probability: the mean of the pieces contained in a pallet has been calculated taking in account the frequency of this one:

$$Items/pallet = \frac{\sum freq.items/pallet}{\sum freq}$$

This methodology intends to spot the most representative products. Once this coefficients is calculated, a uniform distribution is considered for the products in each box so the probability that one box is unable to satisfy the demand is:

$$Pr(X \leq k) = \frac{k-a}{b-a}$$

Where k is items/line, a is 0 and b is the mean of all the coefficients calculated previously.The results show that this probability is very remote, can be considered almost 0 so the assumption will be that the number of stops per batch is equal to the number of lines per batch and there is always enough parts in one line to satisfy the costumer needs.

- The total standard deviation for the AS/RS batch time is:

$$S(\text{S/R bt}) = \sqrt{\frac{\# \frac{lines}{batc\,h}}{\#\text{cranes}}} . S(DC)$$

- An acceleration and deceleration time has been added so the A variable, that is the total acceleration and deceleration time per batch is:

$$A = 6 \,.\, adtime \,.\, \# \frac{lines}{batch}$$

- With these adaptations, the expected total batch time can be calculated using the equations in the previous chapter and the throughput or performance of the system will be measured in lines/hour.

$$Throughput \;= \frac{\left(\# \frac{lines}{batc\,h}\right)}{E(bt)\; in\; hours}$$

2.6 The AS/RS model in Excel

In the article Design and Performance Models for End-of-Aisle Order Picking Systems, Yavuz A. Bozer and John A. White propose an optimization algorithm for determining the minimum number of aisles required. It can be argued that the function to minimize could be the cost of the system, their argument is that the price of the system fluctuates too much depending on market conditions.

The overall vision of the problem is:

$$
\begin{array}{ll}
\text{Minimize} & M \\
\text{Subject to:} & \text{System throughput} \geq R, \\
 & \text{System storage capacity} = S, \\
 & M \quad \text{positive integer.}
\end{array}
$$

Being *M* the number of aisles, *R* the required throughput and *S* the required storage capacity.

It has to be reminded that this model makes the assumption that the number of aisles is equal to the number of pickers. In the model of this Thesis, which has been implemented in Excel, the target is not to minimize just the number of aisles but to minimize both number of aisles and number of pickers. A double-search algorithm has been developed to try all the options among a range of values selected for the user (number of pickers and number of aisles) and check if the throughput reached is bigger than the required.

This way user has a list of combinations of number of aisles and number of pickers that meet the throughput requirements and can choose the most beneficial for his/her case.

The space optimization has also been taken in account in the model. The user is able to introduce the sizes of the modules that will conform the racks. Each module is supposed to store one pallet. The space requirements will be determined for the amount of goods that need to be stored at a time. The user is also able to introduce the expected height of the racks since it has been seen that storing more than seven pallets in a column is not likely in most warehouses. This way, the total volume of the rack-area is determined with this requirements taking in account the number of aisles selected.

The space required for the conveyor belt has not been considered. Instead a total space for each picker is considered and the user can modify it and adapt it to the specific conditions of his/her picking areas. This space will obviously depend on the number of pickers the user chooses to put.

ASRS

Requirements		
# Modules	1767	
# Picking aisles	5	
# Pickers	10	
Module dimensions		
Width (B)	0,9	m
Height racks (H)	2,1	m
Depth racks (D)	1,3	m
Aisle dimensions		
Picking aisle breedte (b)	2	m
B Margin (c)	2	m
Available Height (m)	15	
Total dimensions		
B	23,00	m
L	27	m
Layers	7,00	

Operational characteristics		
Height H	14,7	m
Width L	50	m
Vert. Speed	5	m/s
Horiz. Speed	5	m/s
Pick time	10	s
Setup time	80	s
AS/RS pick time	2	s
AS/RS accele/decel time	0,5	s
Manipulating time C	15,4	s
Calculations		
th	10	
tv	2,94	
T	10	
th/T	1	
tv/T	0,294	
b	0,294	
E(SC)*	1,028812	
E(DC)*	1,37570426	
E(SC)	**10,28812**	
E(DC)	**13,75704**	
# Items/lijn	4,61	
# order lijnen (n)	7	
Items/batch (n')	32	
Times		
Total Pick time	40,2916339	s
Total Retrieval Time	19	s
Cycle T	40,6099521	**s**
THPT	620,537545	**lines/hr**
Required throughput	1089,82	lines/hr
Required throughput + variance safety	1307,78815	lines/hr
Ability check	MISMATCH	

The ASRS model

3. Automated selection aid

The aim of this chapter is to create a tool that makes the election of an Order Picking System or a combination of several of them. The existing design model in Excel, as previously said, was not designed to design a supermarket with several order picking systems or filter by more than one criteria. However, it is reasonable that in designing the picking area, one may want to store the parts in different systems based on multiple criteria such as frequency or size.

A tool that allows this procedure has been created in this Thesis. The two criteria that have been chosen to filter the products are the frequency and the kind of emballage. This tool will be useful in the next chapter, where different configuration will be tried for the design of the supermarket with real data from a manufacturing company. This tool only enables to choose the flow rack system, the VLM and the ASRS that are considered the most representative cases in this case.

Emb type	Frequ	Flowracks	VC	HC	VLM	ASRS	sum
750	Slw Mov	1	0	0	1	0	2
	Fst Mov	1	0	0	1	0	2
780	Slw Mov	1	0	0	1	0	2
	Fst Mov	1	0	0	1	0	2
790	Slw Mov	1	0	0	1	0	2
	Fst Mov	1	0	0	1	0	2
840	Slw Mov	1	0	0	1	0	2
	Fst Mov	1	0	0	1	0	2
L0	Slw Mov	1	0	0	0	1	2
	Fst Mov	1	0	0	0	1	2
L1	Slw Mov	1	0	0	0	1	2
	Fst Mov	1	0	0	0	1	2
L2	Slw Mov	1	0	0	0	1	2
	Fst Mov	1	0	0	0	1	2
L3	Slw Mov	1	0	0	0	1	2
	Fst Mov	1	0	0	0	1	2
L4	Slw Mov	1	0	0	0	1	2
	Fst Mov	1	0	0	0	1	2
L5	Slw Mov	1	0	0	0	1	2
	Fst Mov	1	0	0	0	1	2
K0	Slw Mov	1	0	0	0	1	2
	Fst Mov	1	0	0	0	1	2
K1	Slw Mov	1	0	0	0	1	2
	Fst Mov	1	0	0	0	1	2
K2	Slw Mov	1	0	0	0	1	2
	Fst Mov	1	0	0	0	1	2
L6	Slw Mov	1	0	0	0	1	2
	Fst Mov	1	0	0	0	1	2

Fig. 3.1-This tool enables to filter by type of product and frequency

An automated search engine was implemented to speed up the search of the optimum number of pickers and characteristics of the system up. This search engine is also only available for the flow rack system, the VLM and the ASRS for the same reason. For the flow racks a double search algorithm has been implemented. The user can choose a range of values for the aisles and for the pickers used. All possible combinations are then written down in another sheet as well as the throughput associated to each combination and the surface required. For the ASRS a very similar system exists. For the VLM, the user will be able to choose a range for the number of pickers used. The number of VLMs per pod however has to be determined manually by the user. This can be explained because the results obtained by changing this parameter are very similar and this way the search is faster. The user can also select for each system the expected throughput so that the sum of the three meets the requirements of the general throughput.

Flowracks				ASRS					VLM				
surface	aisles	pickers	check	throughput	surface	aisles	pickers	check	throughput	surface	pods	vlmpod	check
5036,48	1	1	MISMATCH	77,4876157	705	1	1	MISMATCH	458	63,36	2	3	MISMATCH
5036,48	1	2	MISMATCH	77,4876157	725	1	2	MISMATCH	702	95,04	3	3	MISMATCH
4521,68	2	1	MISMATCH	157,0419	730	2	1	OK	948	126,72	4	3	MISMATCH
4521,68	2	2	MISMATCH	249,078451	750	2	2	OK	1199	158,4	5	3	OK
4305,68	5	5	MISMATCH	60	5036,48	1	1	MISMATCH	1452	190,08	6	3	OK
4305,68	5	6	MISMATCH	166	5036,48	1	2	OK	1708	221,76	7	3	OK
4305,68	5	7	MISMATCH	60	4521,68	2	1	MISMATCH	458	63,36	2	3	MISMATCH
4305,68	5	8	MISMATCH	165	4521,68	2	2	OK	702	95,04	3	3	MISMATCH
4305,68	5	9	OK						948	126,72	4	3	MISMATCH
4305,68	5	10	OK						0	158,4	5	3	MISMATCH
4305,68	6	5	MISMATCH						1199	158,4	6	3	OK
4305,68	6	6	MISMATCH						1603	190,08	7	3	OK
4305,68	6	7	MISMATCH						702	95,04	3	3	MISMATCH
4305,68	6	8	MISMATCH						948	126,72	4	3	MISMATCH
4305,68	6	9	OK						1199	158,4	5	3	OK
4305,68	6	10	OK						1452	190,08	6	3	OK
4323,68	7	5	MISMATCH						1708	221,76	7	3	OK
4323,68	7	6	MISMATCH						1972	253,44	8	3	OK
4323,68	7	7	MISMATCH						2236	285,12	9	3	OK
4323,68	7	8	MISMATCH						2495	316,8	10	3	OK
4323,68	7	9	OK										
4323,68	7	10	OK										
4302,08	8	5	MISMATCH										
4302,08	8	6	MISMATCH										
4302,08	8	7	MISMATCH										
4302,08	8	8	MISMATCH										

Required Through	
Flowracks	1000
VLM	1000
ASRS	100

Fig. 3.2-The automated search engine

A manual to explain the use of both the ASRS model and the search engine is available in annex 1 with detailed explanations of the modifications introduced in the Excel model.

4. Design of a Supermarket area: Case study

4.1 Introduction

In this chapter, a case study for a company in the automotive industry is presented. The study will be focused on the design of a supermarket area for an assembly line. Following the methodology proposed by Yoon and Sharp in "A structured procedure for analysis and design of OPS", two configurations for the supermarket area will be proposed.

4.2 Fundamental Aspects

Most studies of conventional warehouse and OPS design imply prescribed sequences of steps in the design process. Such a perspective is inappropriate because of the complexity of an OPS (Yoon and Sharp, 1996). Figure 4.1shows the major factors affecting OPS design.

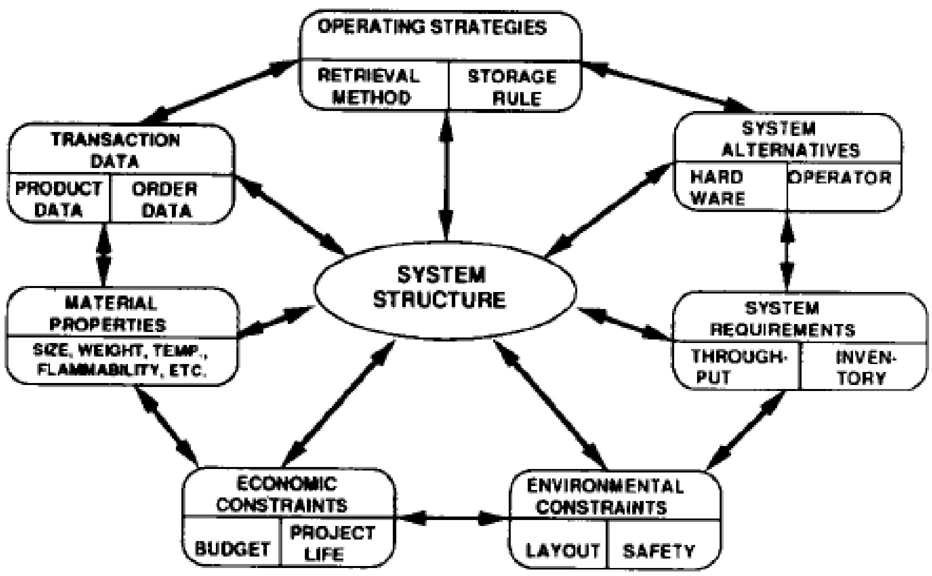

Fig. 4.1- Factors affecting OPS design. "A structured procedure for analysis and design of OPS", Yoon and Sharp 1996.

The constraints that will be more important for the design of the Supermarket are: System requirements, environmental constraints, transaction data and material properties. More precisely, the most important constrains will be the size and weight of the products, the product and order data (such as frequency, items per line…), the spatial constrains and the throughput and inventory requirements. TheEconomical constrains will not be studied deeply due to the lack of a reliable model to measure the costs of the different systems. Also no operating strategies and system alternatives will be used as a constraint because they would exceed the limits of this Thesis.

One of the mainreasons that make the design of an OPS complex is the great variety of equipment types and different material flows. The material flows represent all the possible transformations the load-units can have between their arrival and their departure to, in the case of supermarkets, the assembly line. Yoon and sharp present a general structure of an OPS based on material flows, this structure has been adapted to represent the material flows of the supermarket of this study.

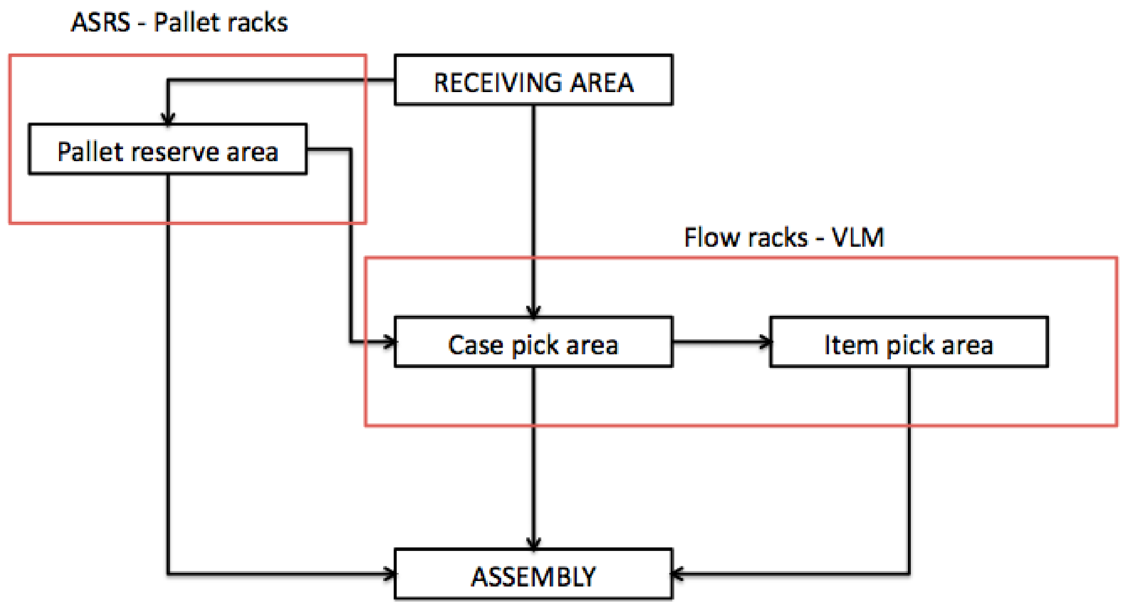

Fig. 4.2- General structure of the case OPS.

Three main flows can be distinguished in this case. The first one is the products that are stored as pallets and are picked directly as a pallet. These products have to be stored in either the ASRS racks, from where they will be carried to the ASRS Picking bay, or in the pallet racks and be picked directly from there. The second products are the ones that are picked directly as a case and they go directly to the assembly line. The last types are the ones that are also in boxes but have to be picked one by one from the box. This two kind of products can either be stored in flow racks or in VLMs.

4.3 The design procedure

The procedure to be followed has three main stages: the input stage, selection stage and evaluation stage. Figure 4.3 shows the diagram of the design procedure.

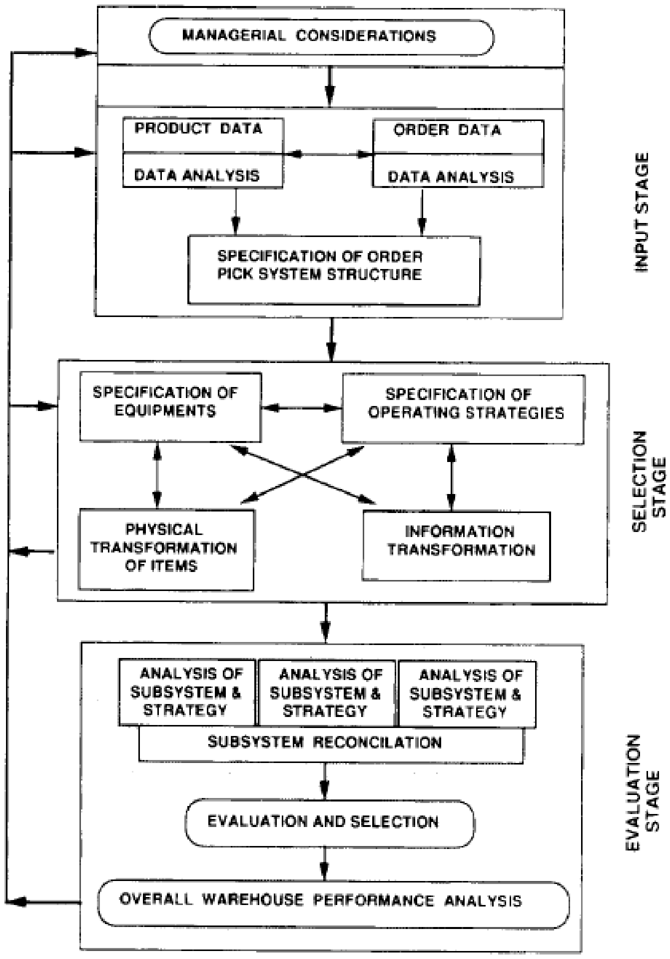

Fig. 4.3- Overview of the design procedure by Yoon and Sharp.

The most important stages and sub-processes will be now explained and followed to design the OPS of the case study. Some of them have been neglected due to the limited information available for this study.

4.3.1 Input stage

Managerial considerations:

The first step in this stage is to determine some managerial considerations. These are the most relevant constrains and they do not need to be very specific. Some examples of managerial considerations would be economic constrains, environmental constrains, system requirements and operational constrains. Below, some of them are specified. It has to be pointed out that economic constrains have been not considered due to the reasons explained in the fundamental aspects chapter.

Environmental constraints	
Total space available	3000 – 6000 m^2
Ceiling height	7 m
Operational constraints	
Shifts	2 of 7,4 hours
Cycle time	6,28 min
Working days per year	110
Number of order classes	1
System requirements	
Storage capacity for Racks and ASRS	40 strikes
Storage capacity for VLM	160 strikes

The storage capacity for the VLMs has been considered greater that the one for other devices, to be precise it is one day of inventory whereas for the other modules is just four hours. It has been considered this way to try to minimize the replenishment operations that are more complicated than in the other systems.

Data analysis:

In this point, the strategy is to analyze both product and order data in order to establishgroups based in common properties. In creating product categories the size of the product has been considered an important parameter (especially if the unit is a pallet or not) because it will determine the possibility for the product to be stored in a particular system. Two categories have, therefore, been created: palletized and non-palletized units.

A second group has been created based on the frequency the parts are moving inside the supermarket. The next table shows the number of products sorted by frequency.

BOXES		PALLETS	
Number	**Freq. <**	**Number**	**Freq. <**
668	**0,1**	479	**0,1**
157	**0,2**	108	**0,2**
85	**0,3**	57	**0,3**
39	**0,4**	26	**0,4**
28	**0,5**	19	**0,5**
14	**0,6**	8	**0,6**
17	**0,7**	14	**0,7**
35	**0,8**	36	**0,8**
45	**0,9**	22	**0,9**
30	**1**	10	**1**
140	**2**	48	**2**
35	**3**	10	**3**
13	**4**	2	**4**
10	**5**	1	**5**
6	**6**	1	**6**
4	**7**	0	**7**
1	**8**	1	**8**
0	**9**	0	**9**
2	**10**	0	**10**
7	**10+**	0	**10+**

This analysis has not been carried out to determine a definitive boundary between fast and slow moving parts. It is useful, however, to make an idea about the range of frequencies that has to be tried in the last stage for obtaining the throughput and space results and validating the model.

There should be also an analysis of the orders made by the assembly line and similar groups should be created taking in account parameters such as lines per order, order volume in cubic meters, percentage in number of orders and items per line. Then, a matrix can be created with the different groups of orders in the rows and the different groups of products in the columns. This would allow to create a even more rigorous classification of scenarios that would lead to a more precise design of the OPS.

This classification will not be carried out because of the complexity it would introduce in the model, which has not been designed to allow such kind of classification. The orders will then be considered homogenous and the parameters items per line or volume per order will be calculated as a mean. Then, the resulting matrix for this case will have only one row and four columns corresponding to the four product groups created.

4.3.2 Selection stage

There are four sub-processes that have to be considered in the selection stage. The interactions between them make it impossible to follow this stage in a sequential path. The strategy will be then to consider them simultaneously and consider the modifications introduced by the decisions made in previous steps. The four sub-processes are: specification of equipment and operating strategies and physical and information transformations.

The specifications in equipment and operating strategies are steps that should be considered for each cell of the matrix named at the previous chapter. In this case there are four cells that have to be examined independently. For the palletized, fast moving parts, the ASRS is considered to be the best choice because it allows a high throughput and can manipulate pallets. For the fast moving boxes, the VLM is assigned because is considered to have equivalent properties as the ASRS but operates with boxes. The slow moving cases and pallets will be assigned to a part-to-picker rack system. This distribution is the one that is intuitively thought to meet the managerial constrains and be the most economically feasible. These assumptions will have to be validated in the last stage. The operating strategies, as it was said in previous chapters will not be taken in account in this case study.

The other two steps are the study of the physical and information transformations. These steps are related to the material flow shown in figure 4.2.As one can see, there are certain products that need to be stored in the supermarket as a palletized unit. These products will have to be stored in the ASRS racks or in the picker-to-parts racks. On the other hand, the products that are picked as a box or a part are required to be stored in flow racks or VLMs. These conclusions match with the choices made in the last steps, therefore, the selection stage is complete and it has to be evaluated in the last stage.

4.3.3 Evaluation stage

This last stage consists in three sub-processes. First, subsystem reconciliation must be carried out, and then there is an evaluation and selection process and finally an overall OPS performance evaluation. The subsystem reconciliation consists in checking the sub-systems requirements and the interactions between them. There are parameters to check such as: cost, space, throughput, check buffer space by measuring the inflows and outflows of the system, check the requirements for the shared equipment (by more than one subsystem), replenishment flows, matching operating strategies, product distribution…

Due to the simplified nature of this case study, all these requirements have been judged to be excessive since a lot of the aspects related to these (buffer space, replenishment, batching policies, operating strategies…) have not been considered. The methodology will be then to assume there is a subsystem compatibility and jump to the last step evaluate the selection made in the previous chapter in terms of overall throughput, space requirements and storage requirements.

Simulation (case 1):

The model will be set then with the configuration described earlier: the fast moving boxes and pallets will be stored in static racks, the fast moving boxes will be stored in the VLMs and the fast moving pallets in the ASR. The fast moving and slow moving boundary will be moved in a range from 0,1 to 1,5 units/hour to consider all possible scenarios. The next graphs show the most important results of the simulation:

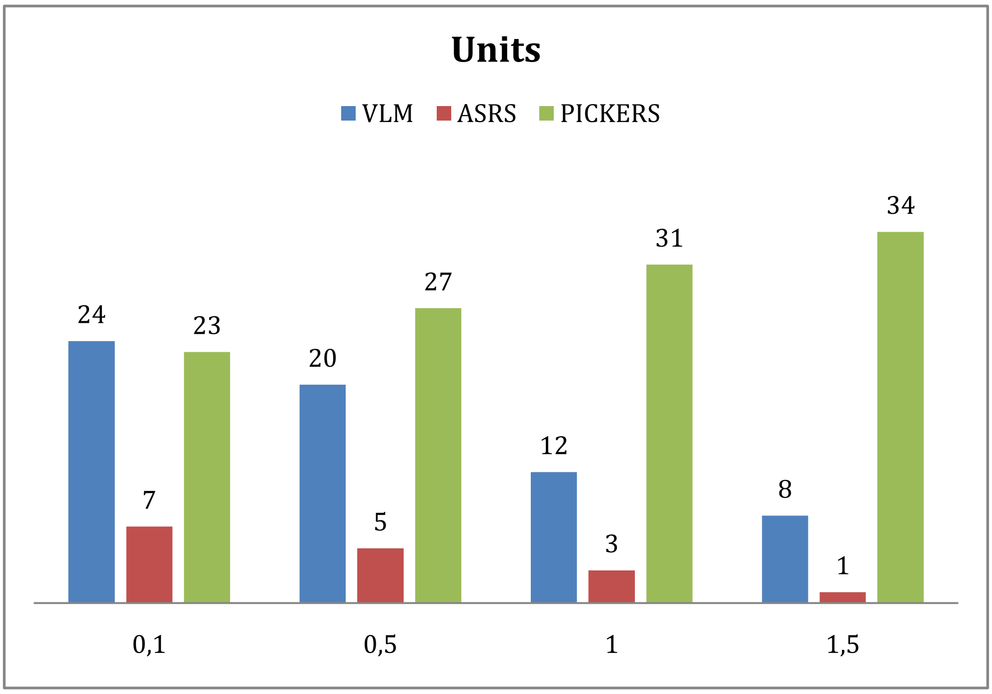

Fig. 4.4- Units needed for the supermarket area depending on the filtering frequency in units/hour for case 1.

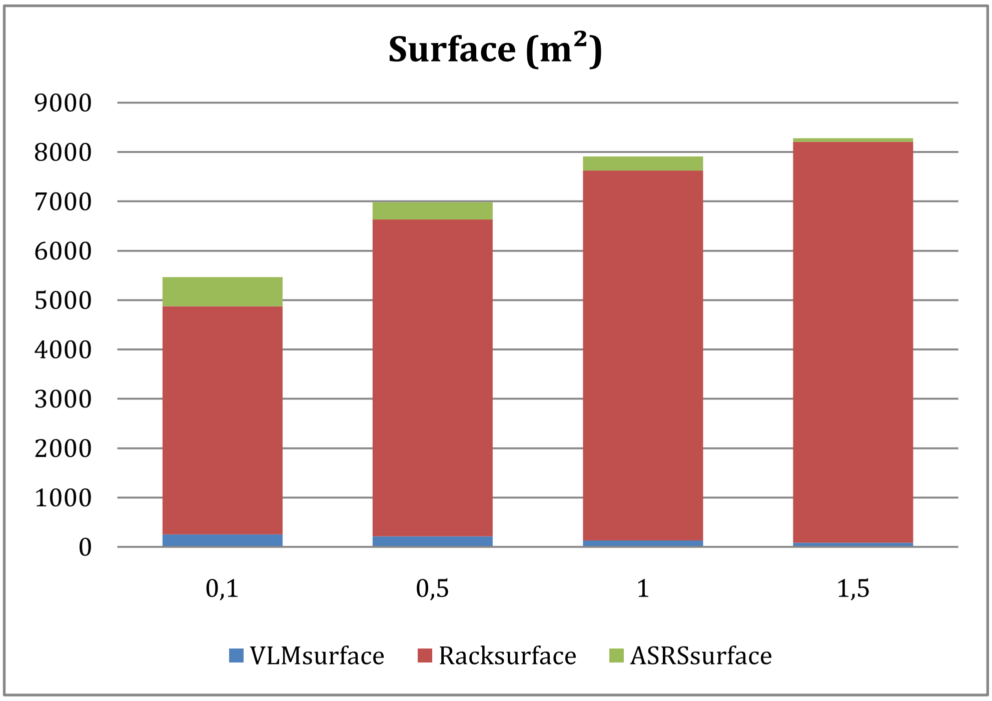

Fig. 4.5- Surface needed for each system depending on the filtering frequency in units/hour for case 1.

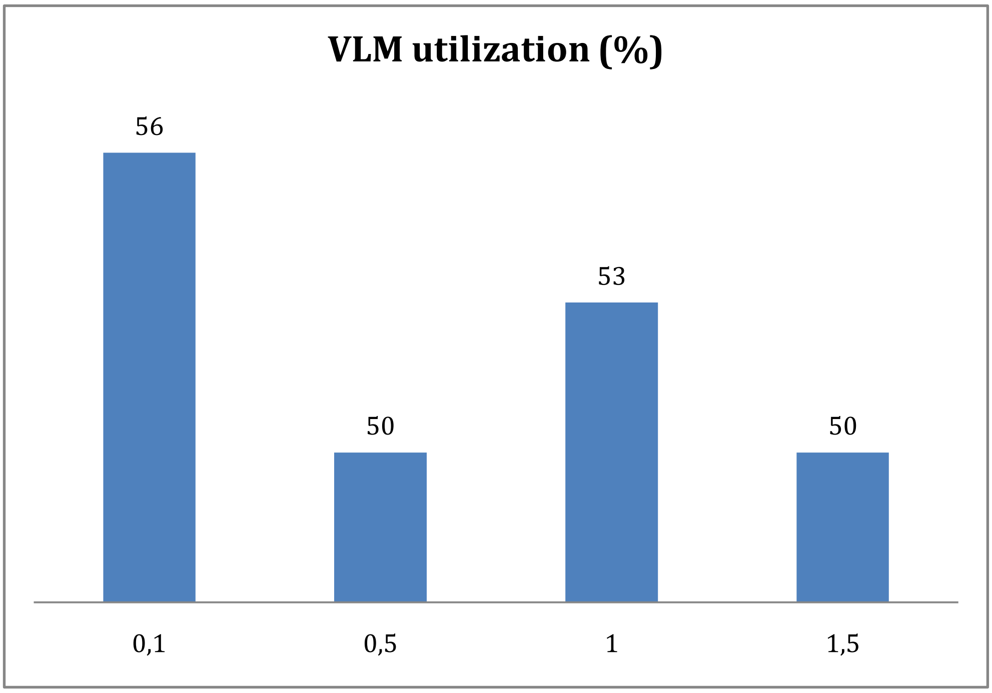

Fig. 4.6-VLM utilization parameter depending on the filtering frequency in units/hour for case 1.

Before going any further, the concept of utilization of storage capacity in the VLMs must be explained. In the previous design model in Excel,the dimensions of the VLM are determined directly by the input data. There are, however, certain parameters of the VLM, such as the height of the picking overture or the height of the shelves that are fix. This leads to impossible results in parts of the throughput calculations that give errors in the final results. The solution has been to leave the height of the module to be determined by the user and give an output parameter that enables the user to know how optimized is the storage space in the VLM. This parameter is the so-called percentage of storage capacity utilization and is calculated comparing the height that a VLM would have given the input parameters defined by the user and the product data and the height defined by the user:

$$\%StorageUtil = \frac{\left(\frac{trays}{VLM}.trayheight\right) + overtureheight}{2.VLMheight}.100$$

The height of the VLM depends on the manufacturer and the kind of machine. For this study, a height of four meters has been considered as a reference because it has been considered to be the more realistic. Other heights can be introduced hence modifying the storage utilization parameter.

The main conclusions that can be extracted of this first simulation are:

- For all cases, the space required for the supermarket area is too high for this case and it is mostly because of the use of racks to store the slow moving parts.

- As more parts are located in the racks (the boundary between fast and slow movers increase), the number of pickers required increases due to the lower productivity of these ones.

- By putting the fast moving parts in the VLMs the utilization parameter is not much greater than half, which means that the VLMs are more or less half empty in all cases. There is a clear compromise between throughput requirements and space optimization, the greater the throughput requirement are, the greater the volume of the parts has to be in order to fill the VLM completely. If a great throughput is needed, a lot of modules will be needed and if the parts are not big, there will be space left in the lifts. It can also be said that very fast moving parts in this assembly line have a very high throughput/volume ratio.

The complete results for the simulation of the two cases are shown in annex 2.

Simulation (case 2):

A second simulation will be carried out to solve the idle space in the VLMs. To do this, another scenario will be proposed: The slow moving boxes will go in the VLMs, the fast moving boxes in flow racks and all the pallets in the ASRS. The operational procedure will be the same as the last case.

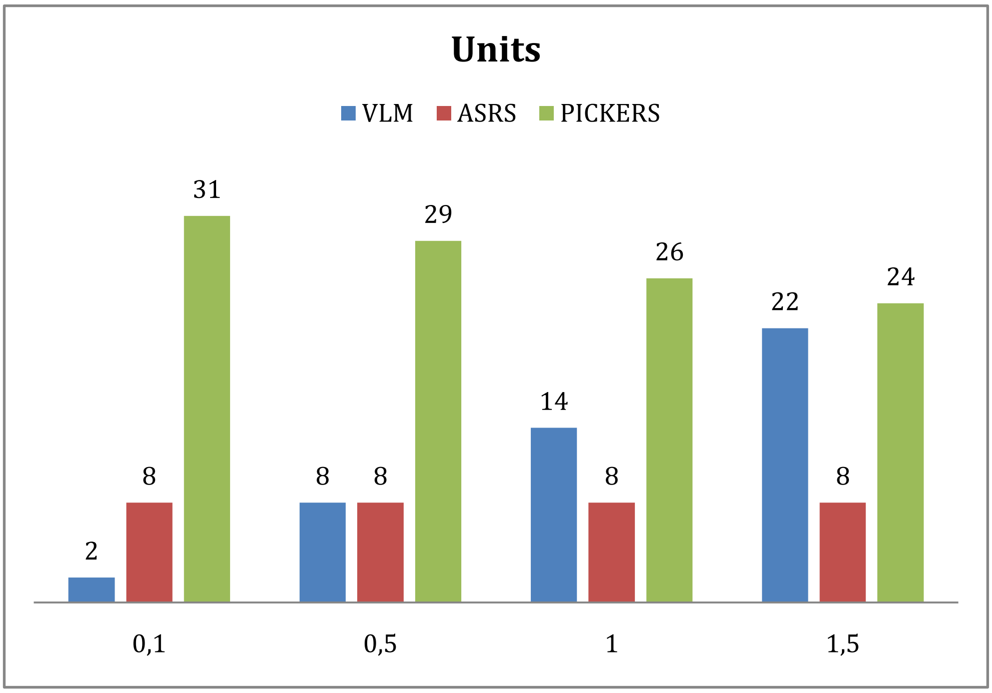

Fig. 4.7- Units needed for the supermarket area depending on the filtering frequency in units/hour for case 2.

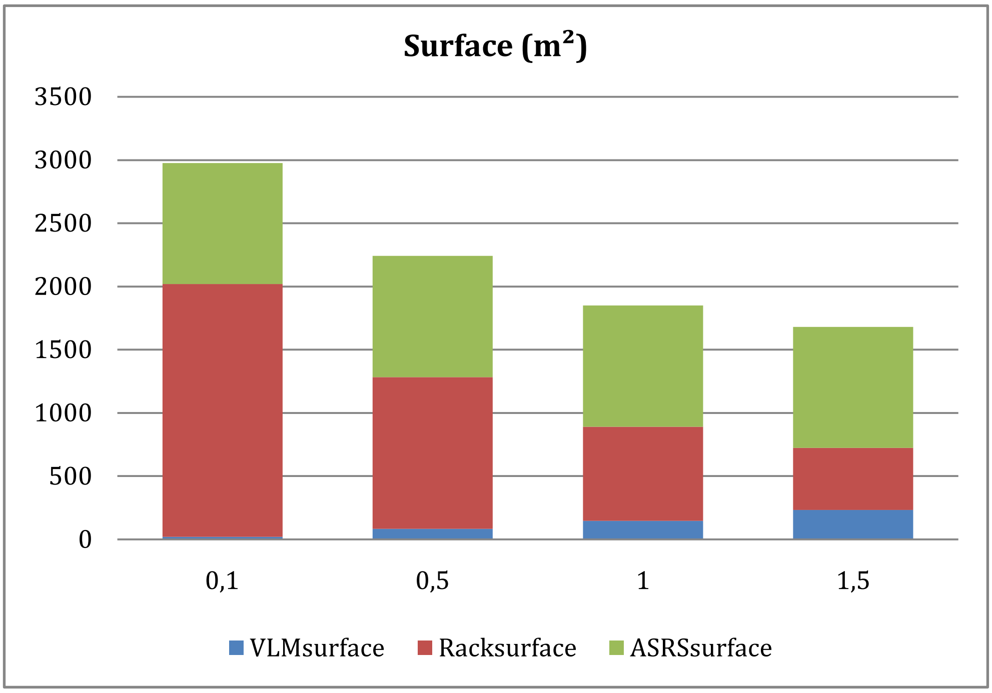

Fig. 4.8- Surface needed for each system depending on the filtering frequency in units/hour for case 2.

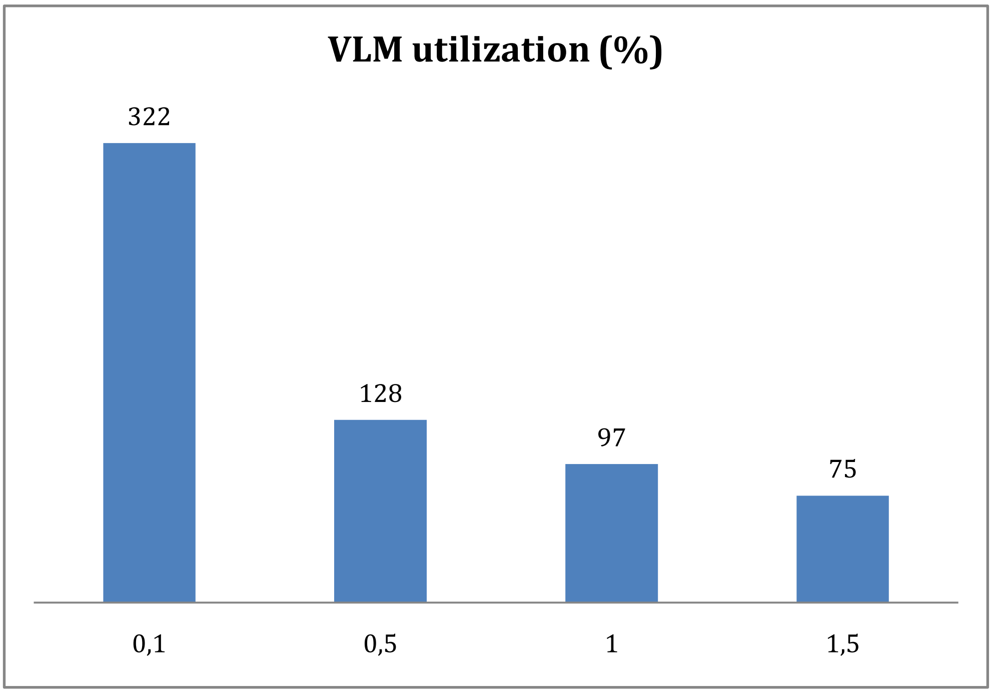

Fig. 4.9- Surface needed for each system depending on the filtering frequency in units/hour for case 2.

By looking at the VLM utilization parameter one can see that by storing extremely slow movers in VLMs, the lifts are not able to store all the parts required with a coherent height. But when storing the slow and moderately fast movers, the utilization is almost total. It can also be appreciated that with the boundary for fast movers set in one, the number of pickers, modules and the space required meets the initial requirements.

The supermarket area would have then flow racks in which the very fast movers will be stored. These parts are mostly case picked which means that the operator does not pick piece by piece but picks a whole box, hence reducing the pick time needed. The low volume of these parts makes it also faster for the pickers to pick the batches because the distances that need to be walked are smaller. A strategy can also be made in order to optimize the picking time for this area and systems like the pick-and-sort and pick-to-box can be utilized.

The VLM would store the slow and moderately fast moving parts resulting in a great space reduction and optimization, a good productivity and a correct utilization of the storage capacity. All pallets would be stored in the ASRS system and sent to pick bays by a conveyor belt.

Another possibility for the design would be to move the extremely slow and fast moving boxes into racks. This can be justified because there are at least 1000 m^2 that are able for the design and are not being used. Moving these boxes (very slow movers) would allow eliminating some VLMs and replacing them for a more cheap way of storage that is available in this case. Following some routing or replenishment strategy, these boxes could be put in the furthest positions of the rack area for example. Calculations made by the model show that putting the very slow movers ($f<0,1$) and the very fast movers ($f>1$) in flow racks will increase the area of the supermarket to 3490 m^2 and would save at least 3 VLMs. The VLM utilization would decrease but no to more than 80%.

A last simulation has been carried out to determine the extreme cases, namely the use of racks exclusively and also the use of only automated parts-to-picker systems. From the first case it can be noticed that the space needed for the area exceeds greatly the initial constrains. The number of pickers is also higher than in any other of the previous simulations.

Only Racks	
Pickers	Surface m²
35	8636

When only parts-to-picker systems are used, the space needed is low and so is the number of pickers. Despite this fact, the utilization of the VLMs is of 70% that means that there are some modules that could be replaced by a cheaper option resulting then, in a more efficient design.

VLM and ASRS	
Pickers	Surface m²
23	1550

These scenarios show that this picking area can't be designed by using only racks, since it would take too much space and work labor. The optimal solution for this case is then to use mostly parts-to-pickers automated equipment and flow racks to optimize the storing capacity of these devices resulting in a more efficient design.

It has to be noted that this design proposals are based on very general parameters and are not presented as an optimal solution. A further economical analysis has to be carried out to determine the costs of equipment, operators, surface… These proposals are then intended to serve as guidelines for future research and a more precise study of the design considering all variables and all situations that have not been considered in this study.

5. Conclusions

A model for the Automatic Storage and Retrieval System was created. The model is an adaptation of a previous existing one and it was implemented in Excel following the design of the existing VLM, carousel, and flow rack models. As a consequence, all possible order picking systems can be considered in the design procedure. Also modifications in the overall design model have been introduced to make the design of an order picking area with multiple systems easier. The new design also allowsthe user to filter products by type of emballage and frequency simultaneously.

The great amount of factors affecting the design of the order picking systems, the variety of them and their complex structure makes it difficult to design an order picking area just by intuition. This fact brings the need of well-structured cognitive procedures for this duty. A case study for the design of a supermarket area for an automotive company was presented and the design was carried out following a structured procedure. For the validation step of the procedure, the modified Excel model was used to check if the suggested designs met the initial constrains.

It can be thought that the high productivity of the VLMs makes them adequate to store the faster moving parts. The simulations carried out to validate the design proposed for the supermarket area of the case study shows that, unlike it can be thought, storing the very fast moving parts in the VLM leads to inefficiencies in storage utilization. This fact can be explained because in supermarkets feeding assembly lines, the frequency of the parts is very high compared to a warehouse and also the volume of the parts is low (at least in this case). The great throughput needed for fast moving parts makes it necessary to have a great number of VLMs that will not be full if the parts are not very big. The simulation also shows that the best solution, without considering economical constrains, is to store the very slow and fast moving boxes in racks, the other boxes in VLMs and all the pallets in ASRS.

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Annex I: Manual

The main features of the modifications introduced in the model are: possibility of obtaining information for designing a picking area with more than one system and double filtering and automated search to detect optimal solutions.

Selection Tool:

The first that will be introduced is the selection tool to filter by product or frequency. It has only been implemented for VLM, flow racks and ASRS. It is important to keep in mind that there was already a tool to enable or disable products based on volume, weight, emballage type, etc. If all the products want to be selected all the cells in this tool have to be filled with a one. It has also been created a table in which the individual throughput and picks per line for every system is shown. No special actions are required for this table because the cells are already connected to the sheets of their respective system. Despite this fact, it can provide important information to the user.

THPT	Orderlijnen/takt-interval	lines/h	Picks/takt-interval box	Picks/takt-interval ind	Picks/orderlijn
FR	0	**0**		0	#DIV/0!
VLM	417,8493	**3992,191**		1129,38	2,702841074
ASRS	190,5271	**1820,322**		232,9967	1,222906109

If the tool needs to be disconnected the only necessary thing to do is to fill all the cells of the matrix with ones, this way the model will go to the same configuration in had previously.

Search Engine:

For the search engine, three programs in Visual Basic were created. This programs stand by the name of: OptimizeVLM, OptimizeFR and OptimizeASRS. To run the programs there are three basic steps:

- There are three sheets in which the results of the throughput and surface needs are shown, one for each system. The sheet's names are FRResult, VLMResult, ASRSResult. In this sheets different parameters are shown and new parameters can be shown easily as well by adding the new variables to the algorithms in Visual Basic. It is recommended to erase all previous searches prior to starting the Macro. The results will then be shown and a final status cell will tell if the solution matches the throughput requirements or not. A sheet that gathers all the result has also been created under the name of vResults, however, I do not recommend its use because it needs modifications for functioning correctly.

- The limits for the search must be specified: for the ASRS and flow rack model the search must be delimited by choosing the rage for the number of aisles and the number of pickers. The search engine will then try all possible combinations among these values. For the VLM, the range must only be specified for the number of pickers because in my personal experience, the optimum results are always obtained with one or two VLMs per pod. This means that this variable will need to be changed manually.

Results in ASRS - Results

Search	From	To
# Picking aisles	7	15
# Pickers	7	15

- When the search limits have been introduced the only remaining thing to do is run the Macro: Developer=>Macros=>Optimize*=>Run. The results will be shown in the corresponding page.